

1 **"PRESSURE-ACTUATED PERFORATION WITH**
2 **CONTINUOUS REMOVAL OF DEBRIS"**
3

4 FIELD OF THE INVENTION

5 This invention relates to a method and apparatus to perforate or re-
6 perforate a well and then to substantially and immediately thereafter circulate a fluid
7 for removal of solids and debris from an underground formation for an aggressive
8 completion or stimulation.

9
10 BACKGROUND OF THE INVENTION

11 To recover hydrocarbons such as oil and natural gas from
12 subterranean formations through a wellbore penetrating the earth to the
13 hydrocarbon-bearing formation, it is common to perform a completion, including
14 perforating, and in some circumstances to perform some type of stimulation
15 procedure in order to enhance the recovery of the valuable hydrocarbons.

16 In order to recover the hydrocarbons, a well is drilled from the surface
17 to the formation. Following drilling, the well is generally completed by installing a
18 tubular well casing in the open borehole and cementing the casing in place.
19 Because the casing and cement forms a continuous hollow column, no wellbore
20 fluids are able to enter the well to be transported to and recovered at the surface.

21 For this reason, it is common to provide openings through the casing
22 and cement annulus in the zone of interest by perforating the casing and cement into
23 the surrounding formation to provide access from the formation into the wellbore for
24 recovery of the formation fluids. In situations where existing perforations are

1 deemed inadequate the formation can be stimulated using a variety of other
2 techniques such as acidizing, fracturing, flushing, or re-perforating, any of which can
3 produce debris.

4 Forms of debris include drilling or perforation debris, debris from
5 cementing operations, and/or mud solids. Naturally occurring debris such as sand,
6 silts or clays can also be present. In some formations shales and shale chunks,
7 pyrite, coal and other fragmented sections of formations can be produced. This
8 debris should be quickly removed from the wellbore or formation in order to prevent
9 it from causing a blockage, or eroding or damaging production equipment. In some
10 instances the removal of increased volume of debris can substantially enhance
11 production.

12 Completion or stimulation methods include a method described in US
13 Patent Re. 34,451 to Donovan et al wherein a perforating gun with an external auger
14 is mounted to a tubing string to both aid in clean-up of the debris from the
15 perforations as well as to facilitate the movement of the gun out of the debris. The
16 auger flights create a tortuous path increasing the velocity of produced formation
17 fluids and improves the ability of those fluids to carry debris. Hydrostatic kill fluid is
18 circulated to remove debris and produced hydrocarbons. Thereafter, proppent is
19 pumped down tubing and into the formation. The auger facilitates the removal of the
20 gun packed in the sand.

21 In US Patent 4,560,000 to Upchurch a well perforating technique
22 actuates a firing mechanism of a tubing-conveyed perforating gun using a pressure
23 difference between at different points in the borehole. The technique obtains the

1 benefit of underbalanced conditions to aid in creating a localized cleansing effect as
2 the formation fluids enter the well casing.

3 Further, Applicant was part of the development of an aggressive
4 perforating-while-foaming (PWF) production process to increase the production
5 capability of a well. This process has gained wide usage over the last 4 years within
6 the heavy oil industry, specifically wells drilled into unconsolidated sandstone
7 formations. This method produced more sand in a shorter period of time than other
8 more traditional methods. It is strongly suspected that this immediate removal of
9 sand is linked to the superior performance of these wells. A perforating gun is tubing
10 conveyed down an underbalanced well. The gun is detonated using a drop bar and
11 remote trigger. Foam is almost simultaneously injected and continuously circulated
12 through the wellbore, carrying with it debris from the formation.

13 Although continuous circulation of foam effectively removes debris
14 from the wellbore in the PWF process, the remote trigger can create un-safe work
15 practices as a result. As well, drop-bars are not considered practical in highly
16 deviated wells since the bar may not reach the bottom. Upchurch relies solely on
17 formation pressure to clean out the wellbore, which can be insufficient in low
18 pressurized formations and can prevent comprehensive elimination of debris from
19 the wellbore. Donovan's method is also dependent on formation pressure to clean
20 out the perforation debris from the wellbore, but is aided by the auger blades.
21 Removal of wellbore debris is not a controlled factor in either case. If debris is not
22 completely removed from the wellbore, it may block perforations, limit production,
23 damage production equipment, or plug the outside or the inside of the production

1 tubing reducing, partially or totally restricting production. In such instances, well
2 clean-out procedures would be repeatedly required at a large expense.

4 SUMMARY OF THE INVENTION

5 A process is described for creating openings in a well casing and
6 which substantially and immediately accommodates clean-up and production of
7 debris. In a preferred embodiment, a pressure-actuated perforating gun is fired
8 adjacent a zone in the formation to be perforated for forming openings. Substantially
9 immediately thereafter, a fluid is continuously injected through a downhole pressure-
10 actuated injection means or port near the openings and is circulated up through a
11 wellbore at a sufficient velocity or elutriation rate overcome settling of debris and
12 therefore to remove and lift debris from the formation. Optionally, an uphole foam
13 injection means or port can aid in adjusting the hydrostatic head above the
14 perforating gun. The tubing string extends sufficiently above the wellbore at surface
15 to enable lowering of the tubing string and downhole injection means or port to
16 below the openings for enhanced removal of debris.

17 In a broad aspect, a process for creating openings between a wellbore
18 and a formation comprises running-in a tubing string into the wellbore to position a
19 perforating gun adjacent a perforating zone, pressurizing to a first pressure to fire
20 the perforating gun and produce openings between the wellbore and the formation,
21 pressurizing to a second pressure to actuate a downhole injection means and
22 injecting fluid therethrough at a sufficient velocity or elutriation rate to convey debris
23 from the wellbore by circulating the fluid out through the downhole injection means of

1 the wellbore to at surface. It is preferable to lower the tubing string during circulation
2 so as to re-position the location of the downhole injection means to below the
3 openings. Typically thereafter the tubing string is then removed.

4 In another broad aspect, an apparatus for creating openings between a
5 wellbore and a formation comprises a tubing string in the casing and extending
6 downhole from surface for positioning a perforating gun adjacent a perforating zone
7 and forming an annulus between the tubing string and the casing, a downhole
8 injection port located on the tubing string for injection of fluid at an elutriation rate so
9 as to continuously remove debris from the wellbore, and means to pressurize the
10 tubing for firing the perforating gun and opening the downhole injection means. An
11 uphole foam injection means can be located on the tubing string for cleaning out the
12 well and displacing wellbore fluid to create a desired fluid level.

1 BRIEF DESCRIPTION OF THE DRAWINGS

2 Figures 1a – 1b are a simplified cross-sections of a wellbore illustrating
3 apparatus run-in on a tubing string for placement of a perforating gun adjacent a
4 formation before firing and for injection fluids, respectively;

5 Figures 2a – 2g are a series of schematics of stages of the
6 methodology according to one embodiment of the invention; and

7 Figure 3a - 3c are flowcharts of some steps of an embodiment of the
8 invention according to Figs. 2a-2g and illustrating some optional embodiments.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference to Fig. 1a, in a preferred embodiment, it is desirable to create openings 10 in a well casing 12 of a wellbore annulus 14 or wellbore 16 adjacent an underground formation 18. Herein, the openings 10 are more conventionally referred to as perforations 20 which enable communication between the wellbore 16 and the formation 18 through the casing 12. Generally, the perforations 20 are created by firing a perforating gun 22 in the wellbore 16. Debris generally exists in the formation and in the casing which results from operations including drilling or perforation debris, debris from cementing operations, and from mud solids. Naturally occurring debris such as sand, silts or clays can also be present in the formation. In some formations shale, shale chunks, pyrite, coal and other fragmented particles of the formation can be produced.

As shown in Fig. 1b and Figs. 2c and 2d, debris is removed by substantially immediately commencing to inject and circulate a fluid 24 at sufficient velocities or rates so as to overcome settling velocities from some or substantially all of the debris for the fluid and lift this debris to surface 26. Such rates are termed herein as elutriation rates.

Fluids 24 are chosen for their elutriation characteristics, such as density, viscosity, and flow velocities as well as how they interact with wellbore fluid 46 and formation fluids 66. The possibility of formation damage should always be considered when choosing a fluid 24. Fluid 24 options can include low density foams, gases, or liquids.

1 As shown in Figs. 1a,1b, the formation 18 and wellbore 16 are
2 prepared for an aggressive completion or stimulation techniques using a preferred
3 embodiment of the present invention. A suitable wellhead configuration comprises a
4 spool 28 having a fluid and debris outlet 30 providing communication with the
5 wellbore 16, a blow-out preventor 32 and a pack-off 34 at a wellhead 36, and a fluid
6 injection inlet 38.

7 With reference also to Figs. 2a-2g and Figs. 3a-3c, a completion is
8 prepared comprising a tubing string 40 fit at its distal end with the pressure-actuated
9 perforating gun 22 set to fire at a first pressure, and a downhole injection means or
10 port 42 set to open or burst at a second pressure. The downhole injection port 42 is
11 located uphole of the perforating gun 22. The tubing string 40 is made up with
12 conventional components to assist in establishing a tubing tally and the like.

13 The apparatus enables injection of fluid 24 for lifting debris from the
14 wellbore 16 such as when there is not sufficient formation production volume or
15 pressure to remove the debris or where the debris has a high enough density to be
16 unaffected by usual formation production. Circulation of a suitable fluid 24 can be
17 implemented providing enhanced lift. Such fluid 24 is circulated at sufficient velocity,
18 viscosity and density or elutriation conditions and rates to remove the debris.

19 Generally, a fluid level 62 is established above the perforating gun 22.
20 Circulation of fluid 24 is established through the fluid injection inlet 38 at the surface
21 26 and wellbore fluid 46 and fluid 24 are recovered through the spool 28 at the
22 surface 26. Additionally, the downhole injection port 42 is preferably a conventional
23 pressure-activated 'S' drain or burst plug 50.

1 At Fig. 2a and step 100 of Fig. 3a (Fig.3a,100), if the well is a good
2 candidate for the operation, the tubing string 40 is run in Fig.3a,101 and preferably
3 positioned Fig.3a,102 in the wellbore 16 such that the perforating gun 22 is located
4 across from a zone 60 to be perforated and is covered by some wellbore fluid 46. Of
5 course, safe procedures must be used in a completions operation or stimulation
6 technique including proper tubing string entry techniques. The tubing string 40 is
7 packed off above the wellbore 16, as shown in Figs. 1a,1b.

8 As shown in Fig. 2b and Fig. 3b at A, if the desired fluid level 62 exists
9 Fig. 3a,103, the tubing string 40 is pressurized using pressurizing means and the
10 perforating gun is actuated. The fluid level 62 creates a minimum hydrostatic
11 pressure above the perforating gun 22 allowing maximum inflow from the formation
12 18 once the formation 18 is perforated, but covers the perforating gun 22 to keep it
13 from splitting.

14 The tubing string 40 is pressurized Fig.3b,104 to the first pressure for
15 actuating a firing head 54 of the perforating gun 22 and forming perforations 20.
16 Activation of the perforating gun 22 is not affected by its orientation in the well casing
17 12. An explosion 64 creating perforations 20 in the well casing 12 between the
18 wellbore 16 and the reservoir or formation 18 for recovery of formation fluids 66.

19 At Fig. 3b,105 if a misfire occurs and the drain 50 is blown or opened,
20 the tubing string 40 needs to be removed and the problem diagnosed Fig. 3b,106. If
21 required, the 'S' drain, burst plug 50 and/or firing head 54 are serviced or replaced.
22 The tubing string 40 is run-in hole and the process starts again.

1 As shown in Fig. 2c, and if there was no misfire, as soon as physically
2 possible, substantially immediately after firing the perforating gun 22, fluid 24 is
3 continued to be pumped into the tubing string 40, applying further pressure
4 Fig.3b,107 to a second pressure, greater than the first pressure, for actuating the
5 pressure-actuated "S" drain or burst plug 50, at the downhole injection port 42
6 enabling fluid communication therethrough with the wellbore 16. A pump, or
7 optionally, pressurized gas may be used to apply pressure in the tubing string 40.

8 Circulation of the fluid 24 conveys or aides the conveyance of the
9 debris up the wellbore 16 to the surface 26 for removal of substantially all debris.

10 Turning to Fig. 2d and to Fig. 3c,108, when circulating fluid 24 and for
11 more effective removal of the debris, the tubing string 40 is slowly lowered so that
12 downhole injection port 42 is below the perforations 20. At Fig. 2e and Fig. 3c,109, it
13 can be desirable in some instances to stroke, or lower and raise, the tubing string 40
14 periodically to prevent lodging of the debris and sand flowing into the wellbore 16
15 between the tubing string 40 and well casing 12. This action can continue until
16 sufficient debris has been successfully removed.

17 Once the operation is complete and sufficient debris has been
18 removed from the wellbore 16, the well's productivity thereafter is increased.

19 At Fig. 2e and Fig. 3c,110 the tubing string 40 is then raised to elevate
20 the perforating gun 22 above the perforations 20. At Fig. 2f and Fig. 3c,111, one of
21 a variety of techniques can be used to apply sufficient hydrostatic head to kill the
22 well before safely pulling Fig. 3c,112 the tubing string 40 from the wellbore 16.
23 Typically the methodology for killing the well is tailored to the particular well and can

1 include simply diminishing fluid 24 circulation to allow formation fluid 66 production
2 to fill the annulus 14 and kill the well or more aggressively load up with suitable
3 wellbore fluid 46.

4 At Fig. 2g, and as an objective of rehabilitating the formation 18, a
5 production string 68 with a production pump 70 can be run in to re-establish
6 production from the treated well.

7 In an alternate embodiment, and returning at Fig. 3a, 103 if the fluid
8 level 62 is deemed inappropriate, and as shown in Fig. 2b the hydrostatic head may
9 be adjusted. If the fluid level is too low Fig. 3a,103,B, conventional wellbore fluid 46
10 can be added Fig. 3b,200 to the wellbore 16 for increasing or creating an optimal
11 fluid level 62 by adding wellbore fluid 46 down the annulus.

12 In another embodiment of the invention, at Figs. 2a,2b and Fig.
13 3a,103,C it may be desirable to reduce the hydrostatic head above the perforating
14 gun 22. An optional uphole injection means or port 44 is located uphole of the
15 downhole injection port 42. The uphole injection port 44 is preferably a conventional
16 rotational valve 48. The rotational valve 48 is strategically located to establish the
17 desired fluid level 62 uphole of the downhole injection port 42 and the perforating
18 gun 22.

19 In Figs. 2a and Fig.3a,101, the tubing string 40 is lowered into the
20 wellbore 16 with the rotational valve 48 in the open position. If the well has not been
21 previously cleaned out, or if too much hydrostatic pressure exists, at Fig.3a,102 a
22 well depth 56 is tagged and low density foam or suitable fluid can be circulated
23 through the rotational valve 48 to displace any wellbore fluid 46 to create the desired

1 fluid level 62. The rotational valve 48 can be positioned at other locations in the
2 wellbore 16 and fluid 24 circulated Fig. 3b,300 to remove wellbore fluid 46 above the
3 rotational valve 48, resulting in the desired fluid level 62. Thereafter, the perforating
4 gun 22 may need to be re-positioned to align with the zone 60 to be perforated.
5 Accordingly, at Fig. 2b and Fig. 3b, 301, the tubing is rotated to close the rotational
6 valve 48, discontinuing any foam injection and creating a continuously sealed tubing
7 string 40 for pressurizing.

8 The preferred fluid 24 is low density foam. Inherently, foam has a high
9 viscosity at low shear rates making it extremely useful as a circulating medium in low
10 pressure reservoirs. These properties minimize fluid loss to the formation and
11 reduce needed annular velocities yet provide sufficient debris elutriation with high
12 lifting capability at minimum circulating pressures. Circulation conditions including
13 foam generated with natural gas or nitrogen instead of air can be used to clean out
14 higher pressure wells.

15 Alternatively, production fluids can also be used. A variety of natural
16 and process additives or polymers are available to increase the lifting, carrying and
17 suspending capability of the fluid.

18 It will be readily apparent to those skilled in the art that many
19 variations, application, modifications and extensions of the basic principles involved
20 in the disclosed embodiments may be made without departing from its spirit or
21 scope.

1 As suggested in Fig. 3a at 100, some wells are better candidates than
2 others for this process, and while this process was developed for the criteria
3 described below, is not limited to these applications which include:

- 4 ▪ Sand production initiation in stubborn sand formations for cold
5 heavy oil production with sand,
- 6 ▪ Known drilling damage completions,
- 7 ▪ Enhanced and rapid drainage geometry development, and
- 8 ▪ Enhanced initial and cumulative production.